Annual Report for Year 1 (03/15/2006 to 03/14/2007)

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Applied Information Systems Research Program

Automated Identification and Characterization of Landforms on Mars

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Summary of objectives

The goal of this project is to use a fusion of methods from the fields of digital terrain analysis, computer vision, and machine learning to develop fully autonomous algorithms for identification and characterization of various landforms on Mars with emphasis on craters and valley networks. Such automation is necessary to provide the scientific community with the ability to process, analyze, and ultimately turn into knowledge a significant portion of the huge amount of spatially extended data collected by spacecrafts orbiting Mars. The project aims at developing robust, "production ready" algorithms, which utilize topographic data over traditionally used imagery.

Progress in Year 1

The timetable for the completion of this project indicated that during the Year 1 the focus will be on developing the core algorithms for identification of craters and, separately, valley networks. We report below on our work toward fulfillment of these goals.

Identification of craters

In the original project we proposed a novel method for identifying craters from topography. In this method craters are delineated by topographic curvature. Thresholding maps of curvature transforms topographic data into a binary image from which craters are identified using a combination of segmentation and detection algorithms. During the Year 1 we have completed the construction of an algorithm based on this method. The complete report is in print in *IEEE Transactions on Geoscience and Remote Sensing*. However, during the course of our investigation we have discovered a more robust method of crater identification. This new method has two stages. The first stage consists of a rule-based algorithm that identifies round depressions in Martian surface and produces a preliminary catalog of crater candidates. The second stage is based on supervised machine learning scheme which is designed to eliminate false negatives from among the crater candidates and produce the final catalog of craters. This new method achieves very good results. We have reported on it at the *2006 Fall AGU Meeting* and made the code publicly available at *cratermatic.sourceforge.net*.

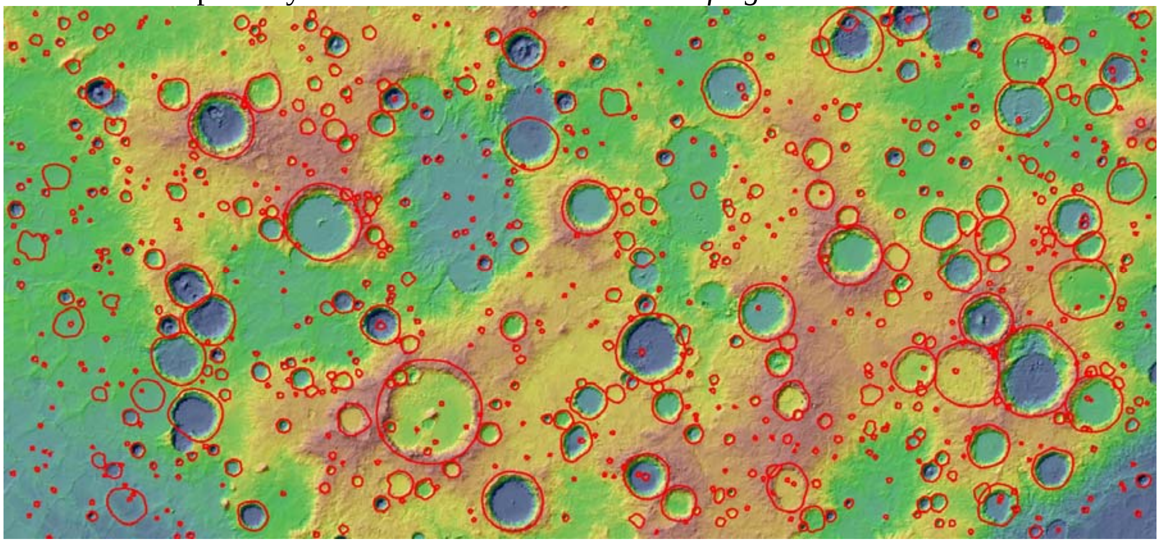

Figure 1: *Craters identified by our algorithm are indicated as red contours on top of MOLA-based color-coded topography. Low-to-high terrain is indicated by blue-to-red gradient.*

Fig. 1 shows an example of our algorithm abilities. The 1 million square kilometers site is located at Terra Cimmeria, Mars. Our algorithm has identified 748 craters versus 571 listed in the existing, manually compiled, catalog (*Catalog of Large Impact Martian Craters* by Nadine Barlow). We have tested our algorithm on six large and diverse sites and its performance is summarized on Fig. 2. On complicated Noachian terrain the performance of our algorithm is comparable to manual counts, it had identified much more small craters, but had failed to detect some large degraded craters. On simpler Hesperian terrain our algorithm is superior to manual counts. An important advantage of our algorithm over existing manual catalogs is its ability to estimate craters depths (because it is based on topographic data). This makes possible the large scale investigations of crater depth-diameter ratio – one of the most important parameter indicating degradational processes and properties of target surface (wet or dry).

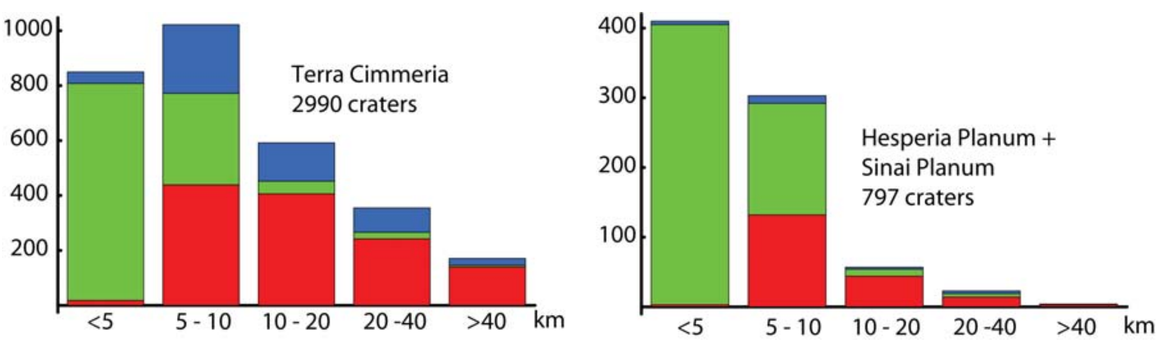

Figure 2: *Comparison of crater counts using our algorithm and Barlow manually compiled catalog. The right site contains comparison of heavily cratered Noachian terrain with many degraded craters. The left site contains comparison of Hesperian terrain dominated by fresh craters. The craters are divided into size (diameter) bins. Red*

bars indicate crater identified by our algorithm and present in the Barlow catalog. Green bars indicate craters identified by our algorithm but absent from Barlow catalog. Blue bars indicate craters not identified by our algorithm but present in the Barlow catalog.

Mapping Valley Networks

In Year 1 we also have developed a novel drainage delineation algorithm specially designed for mapping the Martian valley networks from digital elevation data. Martian valley networks bear some resemblance to terrestrial drainage systems, but their precise origin remains an active research topic. A limited number of valley networks have been manually mapped from images, but the vast majority remains unmapped because standard (terrestrial) drainage mapping algorithms are inapplicable to valleys that are poorly organized and lack spatial integration. Our algorithm first identifies landforms characterized by convex tangential curvature, and then uses a series of image processing operations to separate valleys from other features having a convex form. The final map is produced by reconnecting all valley segments along drainage directions. The complete report on our algorithm is in print in *Computers & Geoscience* Fig. 3 shows illustrates steps implemented by our algorithm (on a typical Martian site) to arrive to a map of valley networks. The algorithm's performance was checked versus manual maps and excellent agreement was found.

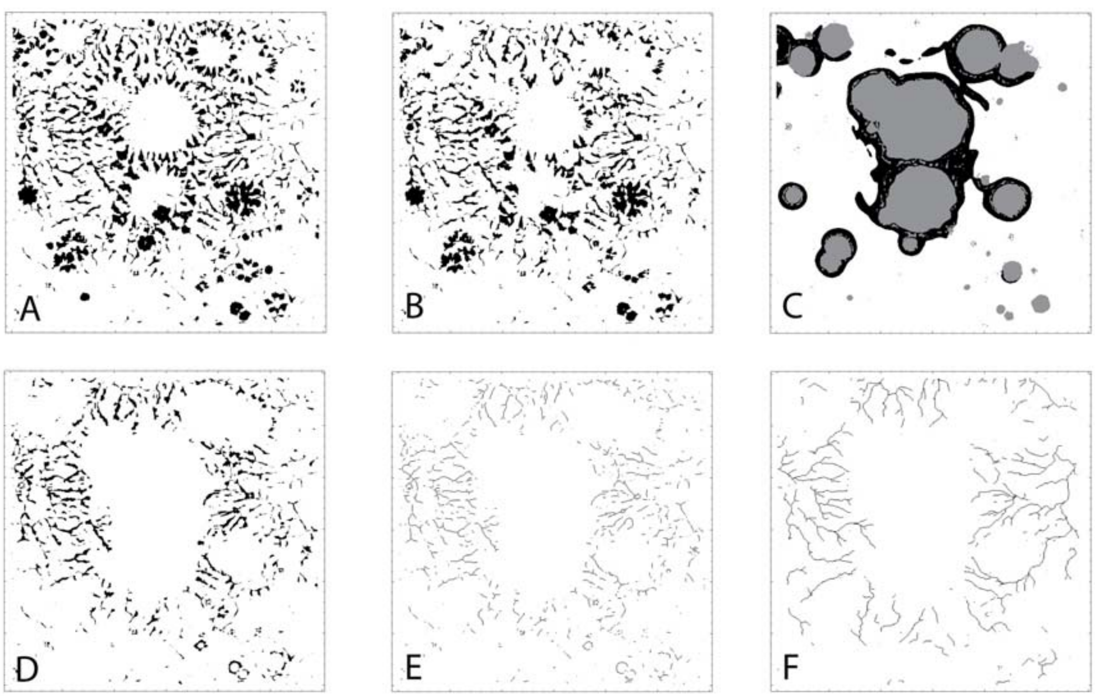

Figure 3: *(A) A binary image of thresholded tangential curvature, black pixels are places where the curvature criterion is fulfilled. (B) A binary image of curvature with circular*

and/or large fragments eliminated. (C) Craters' mask, gray indicates the deep flood component, black indicates the texture component. (D) A binary image of curvature shown in panel B after applying the mask. (E) A binary image of curvature shown in panel D after applying the thinning algorithm. (F) Final map of valley networks after applying the reconnection algorithm to the image shown in panel E.

The algorithm has been applied (*Geophysical Research Letters*) to the Mare Tyrrhenum quadrangle on Mars, yielding a detailed map for the entire quadrangle. Fig. 4 shows a map of valley networks generated by our algorithm versus older manually constructed map. The resultant average value of drainage density for the Noachian part of the quadrangle is an order of magnitude higher than the value inferred from a global map based on Viking images, and comparable to the values inferred from the precision mapping of selected focus sites. Valleys are omnipresent in Noachian terrain even outside the ''highly dissected'' Npld unit. This suggests fluvial erosion throughout the Noachian, implying widespread precipitation. A qualitatively different understanding of climate in Noachian epoch emerges based on new global mapping made possible by our algorithm.

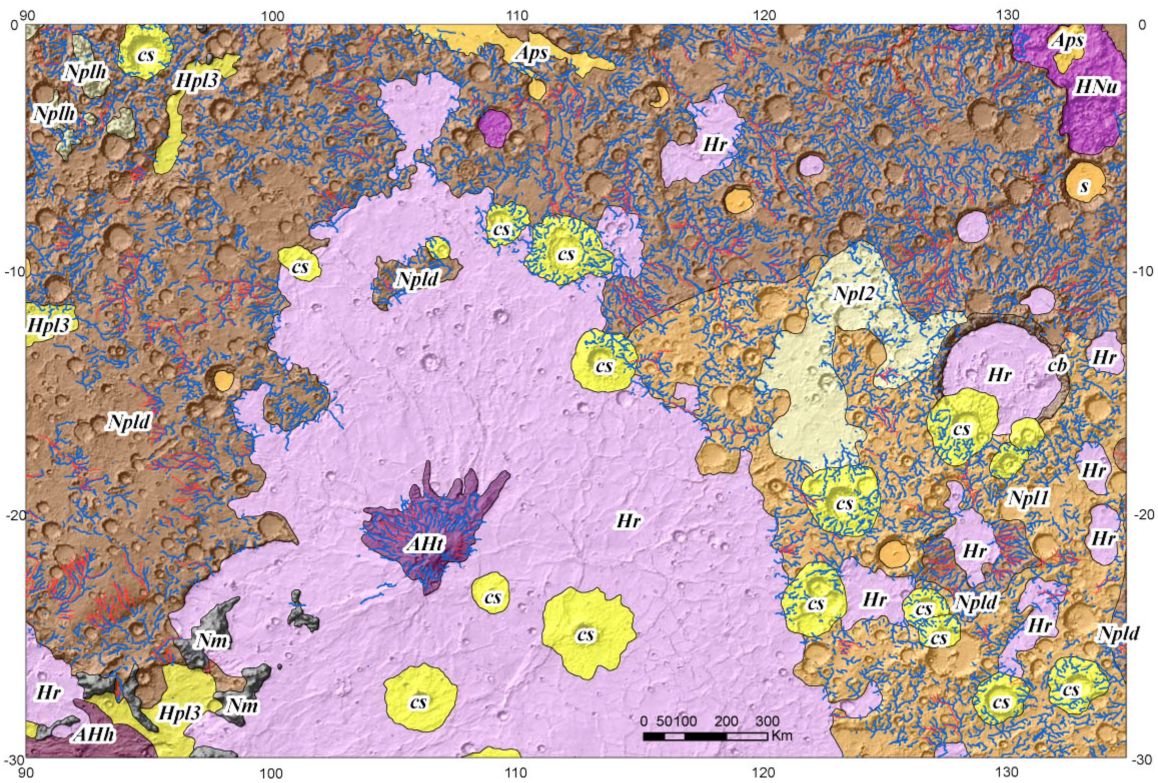

Figure 4: *Map of valley networks in the Mare Tyrrhenum quadrangle on Mars. Blue lines indicate valley networks mapped by our algorithm, red lines indicate valley networks mapped by Carr on the basis of Viking images. Black lines indicate boundaries between geological units, which are marked by different colors.*

Publication:

W. Luo and **T. F. Stepinski** (2006) Topographically Derived Maps of Valley Networks and Drainage Density in the Mare Tyrrhenum Quadrangle on Mars. Geophysical Research Letters, Vol 33, L18202.

B. D. Bue and **T.F. Stepinski** (2006) Machine Detection of Martian Impact Craters from Digital Topography Data. Transactions on Geoscience and Remote Sensing. (in press)

I. Molloy and **T.F. Stepinski** (2006) Automated Mapping of Valley Networks on Mars. Computers & Geoscience. (in press)

Conferences:

B. D. Bue and **T.F. Stepinski** (2006) Machine Detection of Martian Craters from Digital Topography. {In Lunar and Planetary Science XXXVII}, Abstract # 1178.

I. Molloy and **T.F. Stepinski** (2006) Automated Mapping of Valley Networks on Mars. {In Lunar and Planetary Science XXXVII}, Abstract # 1743.

T. F. Stepinski, M. Carriere, and I. Molloy (2006) Properties of Martian Highlands Drainage from THEMIS Images and MOLA Topography. {In Lunar and Planetary Science XXXVII}, Abstract # 1118.

W. Luo, **T. F. Stepinski** (2006) Topographically Derived Maps of Valley Networks and Drainage Density in the Mare Tyrrhenum Quadrangle on Mars. 2006 Fall AGU Meeting, P34B-03.

T. F. Stepinski, M. P. Mendenhall (2006) Robust System for Automated Identification of Martian Impact Craters. 2006 Fall AGU Meeting, P34B-02.

Invited talks:

Robust System for Automatic Identification of Martian Craters from MOLA Data - JPL, September 2006.

The Science and Art of Mapping Martian Valley Networks Using a Computer Algorithm – Smithsonian Institution, Air and Space Museum, Oct 2006.

Machine Identification and Characterization of Martian Craters from Digital Topography – Mars Crater Consortium, Flagstaff Oct 2006.